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U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

*Standard Reference Materials:*

# Glass Fiberblanket SRM for Thermal Resistance

**J.G. Hust**

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[3] Located at Boulder, CO, with some elements at Gaithersburg, MD.

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# Glass Fiberblanket SRM for Thermal Resistance

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## Preface

Standard Reference Materials (SRM's) as defined by the National Bureau of Standards (NBS) are well-characterized materials, produced in quantity and certified for one or more physical or chemical properties. They are used to assure the accuracy and compatibility of measurements throughout the Nation. SRM's are widely used as primary standards in many diverse fields in science, industry, and technology, both within the United States and throughout the world. They are also used extensively in the fields of environmental and clinical analysis. In many applications, traceability of quality control and measurement processes to the national measurement system is carried out through the mechanism and use of SRM's. For many of the Nation's scientists and technologists it is therefore of more than passing interest to know the details of the measurements made at NBS in arriving at the certified values of the SRM's produced. An NBS series of papers, of which this publication is a member, called the NBS Special Publication - 260 Series, is reserved for this purpose.

The 260 Series is dedicated to the dissemination of information on different phases of the preparation, measurement, certification and use of NBS SRM's. In general, much more detail will be found in these papers than is generally allowed, or desirable, in scientific journal articles. This enables the user to assess the validity and accuracy of the measurment processes employed, to judge the statistical analysis, and to learn details of techniques and methods utilized for work entailing the greatest care and accuracy. These papers also should provide sufficient additional information not found on the certificate so that new applications in diverse fields not foreseen at the time the SRM was originally issued will be sought and found.

Inquiries concerning the technical content of this paper should be directed to the author(s). Other questions concered with the availability, delivery, price, and so forth, will receive prompt attention from:

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# Standard Reference Materials: Glass Fiberblanket SRM for Thermal Resistance

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The apparent thermal conductivity data that provide the basis for the certification of glass fiberblanket as an SRM of thermal resistance are reported and analyzed. Detailed analysis and intercomparisons of NBS and other published data are given. These data are represented by an equation describing the dependencies of the data on temperature and density. Certified values of thermal resistance are given for temperatures from 100 to 330 K and densities from 10 to 16 kg/m$^3$.

Key words: apparent thermal conductivity; density; glass fiberblanket; Standard Reference Material; temperature; thermal resistance

## 1. Introduction

The National Bureau of Standards (NBS) has an on-going program to establish physical property Standard Reference Materials (SRM's) as needed to improve measurement reliability. The Center for Chemical Engineering (CCE) has been active in a portion of this effort for about 20 years in establishing SRM's for thermal conductivity over a broad range of conductivities and temperatures. The status of this effort was recently summarized by Hust [1]. The Center for Building Technology (CBT) has supplied calibrated transfer specimens (CTS's) for thermal resistance of insulations for over 50 years.

During the mid 1970's, the American Society for Testing and Materials recognized the strong need for thermal insulation SRM's. As a consequence, a task group was established under the auspices of ASTM subcommittee C16.30 on thermal measurements. The recommendations for establishing thermal insulation SRM's was published in 1978 [2].

The purpose of the present publication is to describe the combined effort of CCE and CBT of NBS to establish the second of a series of insulation SRM's as recommended by the ASTM subcommittee. The first insulation SRM is a glass fiberboard material. It was established as an SRM of thermal resistance by Siu and Hust [3] for the temperature range 255 to 330 K in 1982, and was extended to 100 K in 1985 by Hust [4].

## 2. Material Characterization

In October 1979 two lots of 2.54 cm thick, glass fiberblanket insulation were purchased by the National Voluntary Laboratory Accreditation Program (NVLAP) and the Office of Standard Reference Materials (OSRM) both of NBS. The NVLAP lot was used for proficiency testing. Its density ranged from 8 to 19 kg/m$^3$. The OSRM lot, supplied as 61 x 61 cm square specimens, was to be used as SRM stock and the specimen densities ranged from 12 to 15 kg/m$^3$. The specimens were selected individually from a much larger lot on a criterion of uniformity of density over the center 36 x 36 cm square portions. The material consists of fibrous glass made into a low-density blanket bonded with phenolic resin. The fibers average about 5 μm in diameter and are oriented with their lengths extending primarily parallel to the face of the blanket. The binder content is reported to be about 6% by weight. The selection of this lot is described in detail in reference [14].

## 3. Measurements

The data used for certification of this material were obtained from two NBS apparatus:

a) The CBT 100 cm line source guarded hot plate with a 40 cm diameter meter area. It is described by Powell and Rennex [5]. A smaller version is described by Hahn [6].

b) The CCE 20 cm circular guarded hot plate with a 10 cm diameter meter area. It is described by Smith, Hust, and Van Poolen [7].

During 1980 and 1981 measurements were conducted at CCE on five pairs of specimens from the OSRM material at temperatures ranging from 100 K to 350 K. The test specimens were selected as follows: First, four 61 cm (24 in) squares were selected from the OSRM lot. These four pieces were chosen so their densities spanned the density range of the lot approximately uniformly. The specimen identification numbers wee 81614, 81356, 80156, and 85715. The densities of these specimens were 12.16 (0.759), 13.01 (0.812), 14.24 (0.891), and 14.91 $kg/m^3$ (0.931 $lb/ft^3$), respectively. These four pieces were cut into 11.7 cm (4.6 in) squares and the area density of each piece was determined. Five sets of matched pairs of specimens were selected from the 11.7 cm squares. This size was chosen so that the specimens spanned the gap between the meter and guard portions of the guarded hot plate. Guard frames were prepared from the same material to fill the remaining space between the hot and cold plates. These specimens ranged in density from 10.5 to 16 $kg/m^3$. The CCE measurements were conducted with various fill gases (air, nitrogen, argon, and helium) and over a range of fill-gas pressure from atmospheric pressure to high vacuum. The CCE measurements also involved a range of temperature differences between the hot cold plates from as small as 10 K to as large as 100 K. These variations in test conditions were helpful in separating the heat transfer mechanisms in this material. These data by CCE have been reported [8, 9, and 10]. The atmospheric pressure data with air as the fill-gas are listed in Tables 1 and 2.

More recently, CBT measured twenty-eight pairs of specimens from the OSRM lot using the 100 cm GHP [5]. These specimens included densities from 12 to 15 $kg/m^3$. All of the CBT measurements, listed in Table 3, were performed at 297 K with air as the fill-gas. The specimens were selected to span the entire density range of the lot. The densities given in Table 3 are for the entire 61 cm square specimens.

## 4. Data Analysis

This report serves as the basis of the certification of this SRM over the temperature range 100 to 330 K with air as the fill-gas at atmospheric pressure and a plate emittance of 0.8.

Table 1. CCE thermal conductivity data for glass fiberblanket (Set 1).

| $T_{mean}$ (K) | $T_{hot}$ (K) | $T_{cold}$ (K) | Density ($kg/m^3$) | Thickness (cm) | $\lambda_{obs}$ ($mW \cdot m^{-1} \cdot K^{-1}$) | Percent Deviation |
|---|---|---|---|---|---|---|
| 299 | 311.448 | 286.362 | 14.75 | 2.5892 | 39.970 | -1.15 |
| 299 | 311.453 | 286.427 | 14.75 | 2.5892 | 40.356 | -0.20 |
| 299 | 311.368 | 286.439 | 14.75 | 2.5892 | 40.484 | 0.14 |
| 249 | 260.599 | 238.257 | 14.76 | 2.5874 | 31.205 | 1.82 |
| 100 | 108.943 | 91.068 | 14.79 | 2.5824 | 10.250 | -4.07 |
| 97 | 108.753 | 84.785 | 14.79 | 2.5823 | 10.255 | -0.79 |
| 97 | 108.866 | 84.326 | 14.79 | 2.5823 | 10.370 | 0.49 |
| 111 | 123.378 | 98.174 | 14.79 | 2.5828 | 11.753 | -0.89 |
| 111 | 123.287 | 98.269 | 14.79 | 2.5828 | 11.931 | 0.62 |
| 124 | 136.242 | 111.392 | 14.79 | 2.5832 | 13.386 | 0.18 |
| 136 | 148.977 | 123.504 | 14.79 | 2.5835 | 14.940 | 0.49 |
| 149 | 161.313 | 135.979 | 14.78 | 2.5839 | 16.588 | 1.00 |
| 162 | 174.164 | 149.286 | 14.78 | 2.5844 | 18.106 | 0.01 |
| 174 | 186.811 | 161.806 | 14.78 | 2.5848 | 19.696 | -0.28 |
| 187 | 199.531 | 174.611 | 14.78 | 2.5852 | 21.366 | -0.37 |
| 187 | 199.399 | 174.010 | 14.78 | 2.5852 | 21.275 | -0.56 |
| 200 | 212.040 | 187.211 | 14.77 | 2.5856 | 23.012 | -0.57 |
| 212 | 224.628 | 199.894 | 14.77 | 2.5861 | 24.853 | -0.20 |
| 225 | 237.177 | 212.043 | 14.77 | 2.5865 | 26.673 | -0.09 |
| 237 | 249.758 | 225.170 | 14.77 | 2.5870 | 28.793 | 0.42 |
| 250 | 262.310 | 237.589 | 14.76 | 2.5874 | 30.910 | 0.58 |
| 251 | 261.442 | 239.802 | 14.76 | 2.5874 | 31.068 | 0.74 |
| 262 | 274.855 | 249.807 | 14.76 | 2.5879 | 33.145 | 0.67 |
| 275 | 287.504 | 262.484 | 14.76 | 2.5883 | 35.618 | 0.78 |
| 288 | 300.073 | 275.064 | 14.76 | 2.5888 | 38.048 | 0.32 |
| 300 | 312.537 | 287.671 | 14.75 | 2.5893 | 40.858 | 0.39 |
| 313 | 325.127 | 300.282 | 14.75 | 2.5898 | 43.680 | 0.02 |
| 325 | 337.512 | 312.764 | 14.75 | 2.5903 | 47.052 | 0.55 |
| 336 | 350.058 | 322.678 | 14.75 | 2.5907 | 49.957 | 0.35 |
| 350 | 362.512 | 337.764 | 14.74 | 2.5913 | 54.043 | 0.71 |
| 315 | 335.306 | 294.375 | 14.75 | 2.5899 | 44.380 | 0.27 |
| 330 | 362.339 | 297.060 | 14.75 | 2.5904 | 48.243 | 0.10 |
| 357 | 362.637 | 350.773 | 14.74 | 2.5915 | 56.191 | 1.12 |
| 350 | 356.040 | 344.026 | 14.74 | 2.5913 | 53.903 | 0.56 |
| 338 | 349.850 | 325.269 | 14.74 | 2.5908 | 49.172 | -1.92 |
| 337 | 349.523 | 325.165 | 14.74 | 2.5907 | 51.708 | 3.20 |
| 313 | 325.093 | 300.323 | 13.67 | 2.7938 | 44.886 | -0.05 |
| 325 | 337.730 | 312.757 | 13.67 | 2.7944 | 48.037 | -0.41 |
| 338 | 350.061 | 325.083 | 13.67 | 2.7949 | 51.555 | -0.29 |
| 350 | 362.525 | 337.771 | 13.67 | 2.7954 | 55.430 | -0.04 |
| 300 | 309.293 | 290.863 | 13.68 | 2.7933 | 41.650 | -0.21 |
| 350 | 362.489 | 338.093 | 13.81 | 2.7954 | 55.705 | 0.83 |
| 325 | 337.504 | 313.172 | 13.81 | 2.7944 | 48.261 | 0.41 |
| 300 | 312.496 | 288.474 | 13.82 | 2.7933 | 41.956 | 0.61 |
| 149 | 161.174 | 136.068 | 13.85 | 2.7875 | 16.208 | -1.18 |
| 149 | 161.936 | 136.427 | 13.85 | 2.7876 | 16.938 | 2.75 |
| 162 | 174.180 | 149.132 | 13.85 | 2.7880 | 18.289 | 0.96 |
| 174 | 199.768 | 149.231 | 13.84 | 2.7885 | 19.900 | 0.62 |
| 187 | 224.455 | 149.024 | 13.84 | 2.7889 | 21.533 | 0.72 |
| 195 | 241.527 | 149.199 | 13.84 | 2.7892 | 22.763 | 0.82 |
| 199 | 249.525 | 149.056 | 13.84 | 2.7894 | 23.312 | 0.70 |
| 212 | 274.651 | 149.271 | 13.84 | 2.7898 | 25.314 | 0.62 |
| 244 | 299.737 | 187.458 | 13.83 | 2.7910 | 30.361 | -0.78 |
| 262 | 324.765 | 199.559 | 13.83 | 2.7918 | 33.962 | -1.01 |
| 275 | 349.719 | 199.809 | 13.82 | 2.7923 | 36.605 | -1.81 |

Percent Deviation = $(\lambda_{obs}-\lambda_{calc})100/\lambda_{calc}$

Table 2. CCE thermal conductivity data for glass fiberblanket (Set 2).

| $T_{mean}$ (K) | $T_{hot}$ (K) | $T_{cold}$ (K) | Density ($kg/m^3$) | Thickness (cm) | $\lambda_{obs}$ ($mW \cdot m^{-1} \cdot K^{-1}$) | Percent Deviation |
|---|---|---|---|---|---|---|
| 112 | 124.141 | 99.248 | 10.65 | 2.5828 | 11.976 | 2.95 |
| 149 | 161.282 | 136.046 | 10.64 | 2.5839 | 16.843 | 1.94 |
| 199 | 212.049 | 186.900 | 10.64 | 2.5856 | 24.175 | -0.37 |
| 250 | 262.297 | 237.813 | 10.63 | 2.5874 | 33.316 | -0.95 |
| 300 | 312.381 | 287.707 | 10.62 | 2.5893 | 45.406 | -1.64 |
| 111 | 123.599 | 98.585 | 11.65 | 2.5828 | 11.777 | 1.39 |
| 149 | 161.547 | 137.084 | 11.65 | 2.5840 | 17.043 | 2.98 |
| 200 | 212.028 | 187.237 | 11.64 | 2.5856 | 24.100 | 0.84 |
| 250 | 262.157 | 237.405 | 11.63 | 2.5874 | 33.079 | 1.30 |
| 300 | 312.516 | 287.932 | 11.62 | 2.5893 | 44.767 | 0.65 |
| 111 | 123.154 | 98.367 | 15.95 | 2.5828 | 11.881 | -0.84 |
| 149 | 161.604 | 136.697 | 15.94 | 2.5840 | 16.785 | 1.53 |
| 200 | 212.063 | 187.456 | 15.93 | 2.5856 | 23.020 | 0.05 |
| 250 | 262.271 | 237.740 | 15.92 | 2.5874 | 30.738 | 1.55 |
| 300 | 312.432 | 287.704 | 15.91 | 2.5893 | 40.290 | 1.39 |
| 112 | 123.844 | 100.088 | 13.67 | 2.5828 | 11.659 | -1.89 |
| 149 | 161.690 | 136.757 | 13.66 | 2.5840 | 16.427 | -0.31 |
| 200 | 212.038 | 187.418 | 13.65 | 2.5856 | 23.238 | -0.53 |
| 250 | 262.292 | 238.163 | 13.64 | 2.5874 | 31.600 | 0.79 |
| 301 | 312.705 | 289.380 | 13.63 | 2.5893 | 41.740 | -0.72 |
| 325 | 337.474 | 312.600 | 13.63 | 2.5903 | 48.794 | 1.15 |
| 325 | 337.396 | 312.691 | 13.63 | 2.5903 | 48.603 | 0.75 |
| 325 | 337.363 | 312.854 | 13.63 | 2.5903 | 48.256 | 0.01 |
| 325 | 337.354 | 312.857 | 13.63 | 2.5903 | 48.280 | 0.06 |
| 325 | 337.351 | 312.858 | 13.63 | 2.5903 | 48.288 | 0.07 |
| 325 | 337.349 | 312.856 | 13.63 | 2.5903 | 48.288 | 0.08 |
| 325 | 337.357 | 312.848 | 13.63 | 2.5903 | 48.256 | 0.01 |
| 325 | 337.343 | 312.850 | 13.63 | 2.5903 | 48.287 | 0.08 |
| 200 | 212.220 | 188.514 | 13.65 | 2.5857 | 23.334 | -0.51 |
| 200 | 212.263 | 188.482 | 13.65 | 2.5857 | 23.200 | -1.10 |
| 200 | 212.272 | 188.540 | 13.65 | 2.5857 | 23.247 | -0.91 |
| 200 | 212.253 | 188.592 | 13.65 | 2.5857 | 23.317 | -0.62 |
| 200 | 212.274 | 188.583 | 13.65 | 2.5857 | 23.228 | -1.01 |
| 200 | 212.303 | 188.594 | 13.65 | 2.5857 | 23.209 | -1.11 |
| 200 | 212.249 | 188.551 | 13.65 | 2.5857 | 23.220 | -1.03 |
| 200 | 212.272 | 188.544 | 13.65 | 2.5857 | 23.192 | -1.15 |
| 200 | 212.268 | 188.545 | 13.65 | 2.5857 | 23.196 | -1.14 |
| 325 | 336.894 | 313.263 | 13.63 | 2.5903 | 48.103 | -0.29 |
| 325 | 336.831 | 312.958 | 13.63 | 2.5903 | 47.966 | -0.47 |
| 325 | 336.939 | 313.594 | 13.63 | 2.5903 | 48.233 | -0.12 |
| 325 | 337.035 | 313.292 | 13.63 | 2.5903 | 48.136 | -0.27 |
| 326 | 337.398 | 313.676 | 13.63 | 2.5903 | 48.472 | 0.21 |
| 151 | 163.891 | 137.402 | 13.66 | 2.5840 | 16.623 | -0.24 |
| 351 | 362.502 | 338.916 | 13.62 | 2.5913 | 56.480 | 1.36 |
| 325 | 336.865 | 314.109 | 13.63 | 2.5903 | 47.087 | -2.69 |

Percent Deviation = $(\lambda_{obs}-\lambda_{calc})100/\lambda_{calc}$

Table 3. CBT thermal conductivity data for glass fiberblanket.

| $T_{mean}$ (K) | $T_{hot}$ (K) | $T_{cold}$ (K) | Density ($kg/m^3$) | Thickness (cm) | $\lambda_{obs}$ ($mW \cdot m^{-1} \cdot K^{-1}$) | Percent Deviation |
|---|---|---|---|---|---|---|
| 297 | 311.00 | 283.20 | 14.90 | 2.540 | 39.06 | -1.86 |
| 297 | 311.00 | 283.20 | 12.20 | 2.540 | 42.24 | -1.06 |
| 297 | 311.00 | 283.20 | 13.80 | 2.540 | 40.13 | -1.70 |
| 297 | 311.00 | 283.20 | 13.30 | 2.540 | 40.83 | -1.26 |
| 297 | 311.00 | 283.20 | 14.90 | 2.540 | 39.70 | -0.21 |
| 297 | 311.00 | 283.20 | 13.90 | 2.540 | 40.94 | 0.56 |
| 297 | 311.00 | 283.20 | 12.90 | 2.540 | 41.76 | -0.10 |
| 297 | 311.00 | 283.20 | 12.80 | 2.540 | 42.24 | 0.75 |
| 297 | 311.00 | 283.20 | 12.30 | 2.540 | 42.60 | 0.11 |
| 297 | 311.00 | 283.20 | 13.20 | 2.540 | 41.43 | -0.06 |
| 297 | 311.00 | 283.20 | 12.60 | 2.540 | 42.25 | 0.19 |
| 297 | 311.00 | 283.20 | 12.80 | 2.540 | 41.86 | -0.15 |
| 297 | 311.00 | 283.20 | 12.70 | 2.540 | 42.52 | 1.12 |
| 297 | 311.00 | 283.20 | 13.20 | 2.540 | 41.71 | 0.61 |
| 297 | 311.00 | 283.20 | 14.30 | 2.540 | 40.68 | 0.88 |
| 297 | 311.00 | 283.20 | 13.10 | 2.540 | 42.24 | 1.59 |
| 297 | 311.00 | 283.20 | 12.80 | 2.540 | 41.57 | -0.85 |
| 297 | 311.00 | 283.20 | 12.70 | 2.540 | 41.97 | -0.18 |
| 311 | 321.03 | 301.03 | 13.18 | 2.528 | 43.86 | -2.81 |
| 297 | 307.03 | 287.03 | 13.18 | 2.539 | 41.35 | -0.51 |
| 273 | 283.15 | 263.15 | 13.18 | 2.535 | 35.30 | -2.36 |
| 273 | 283.15 | 263.15 | 13.18 | 2.558 | 35.60 | -1.50 |
| 311 | 320.96 | 300.96 | 12.15 | 2.543 | 46.81 | 0.51 |
| 297 | 307.04 | 287.04 | 12.15 | 2.541 | 42.65 | -0.46 |
| 273 | 283.21 | 263.21 | 12.15 | 2.570 | 36.38 | -2.01 |
| 311 | 321.02 | 301.02 | 14.86 | 2.532 | 43.82 | 1.55 |
| 297 | 307.06 | 287.06 | 14.86 | 2.551 | 40.19 | 0.72 |
| 273 | 283.12 | 263.12 | 14.86 | 2.580 | 34.73 | -0.47 |

Percent Deviation = $(\lambda_{obs}-\lambda_{calc})100/\lambda_{calc}$

To facilitate comparison of the data and to provide a basis for the certification, a model was selected and optimized to represent the data. A variety of models from the literature were examined for this purpose. None of them proved adequate for the entire temperature range of this certification. As a consequence, modification of the form presented for the certification of the glass fiberboard SRM [4] was used. This model described the 128 GHP data points from CCE and CBT with no systematic deviations either as a function of temperature (from 100 to 350 K) or a function of density (from 10.5 to 16 kg/m$^3$). The model is given by equation (1).

$$\lambda(T,\rho) = a_1 + a_2\rho + a_3T + a_4T^3/\rho + a_5\exp -[(T-180)/75]^2 \qquad (1)$$

where the values of the parameters, $a_i$, are $a_1$ = -0.1059, $a_2$ = 0.1378, $a_3$ = 0.07714, $a_4$ = 8472.10$^{-9}$, and $a_5$ = 1.339, $\rho$ is the bulk density in kg/m$^3$, T is temperature in K, and $\lambda(T,\rho)$ is the apparent thermal conductivity in mW$\cdot$m$^{-1}\cdot$K$^{-1}$

The deviations of the data from this model are shown in figure 1 as a function of temperature, and in figure 2 as a function of bulk density. The two standard deviation values computed from the residuals of the fit is 2.1%. For illustration, values of $\lambda(T,\rho)$ are calculated and plotted in figure 3 as a function of temperature at a density of 13 kg/m$^3$, and in figure 4 as a function of density at a temperature of 300 K.

Although the deviations shown in figures 1 and 2 appear random, systematic differences between the CCE and CBT data as a function of temperature are noted. A similar difference in the slope as a function of temperature was noted in the data for the glass fiberboard SRM 1450b [4]. The source of this systematic difference is unknown, but it is less than the overall scatter of the data sets.

## 5. Comparisons

It is desirable to compare equation (1) to the results from other measurements on similar materials. It is most convenient to make these comparisons of $\lambda(T,\rho)$ through the use of the models. The baseline for these comparisons will be the values as calculated from equation (1).

The most direct comparison that can be made is with respect to the recently completed round robin on low-density glass fiberblanket materials as reported by Hust and Pelanne [11]. Part of these measurements were performed on the NVLAP material obtained from the same supplier as was the OSRM material. The data used to develop the model reported by Hust and Pelanne [11] included temperatures from 255 to 330 K, and densities from 11 to 35 kg/m$^3$. The comparison of the two models as a function of temperature for a density of 13 kg/m$^3$ is shown in figure 5. The comparison as a function of density at a temperature of 300 K is shown in figure 6.

Systematic differences between the two equations of as much as 2% are noted at the lower densities. The agreement is excellent at the higher densities. Since part of the material used in the round robin was similar to the material

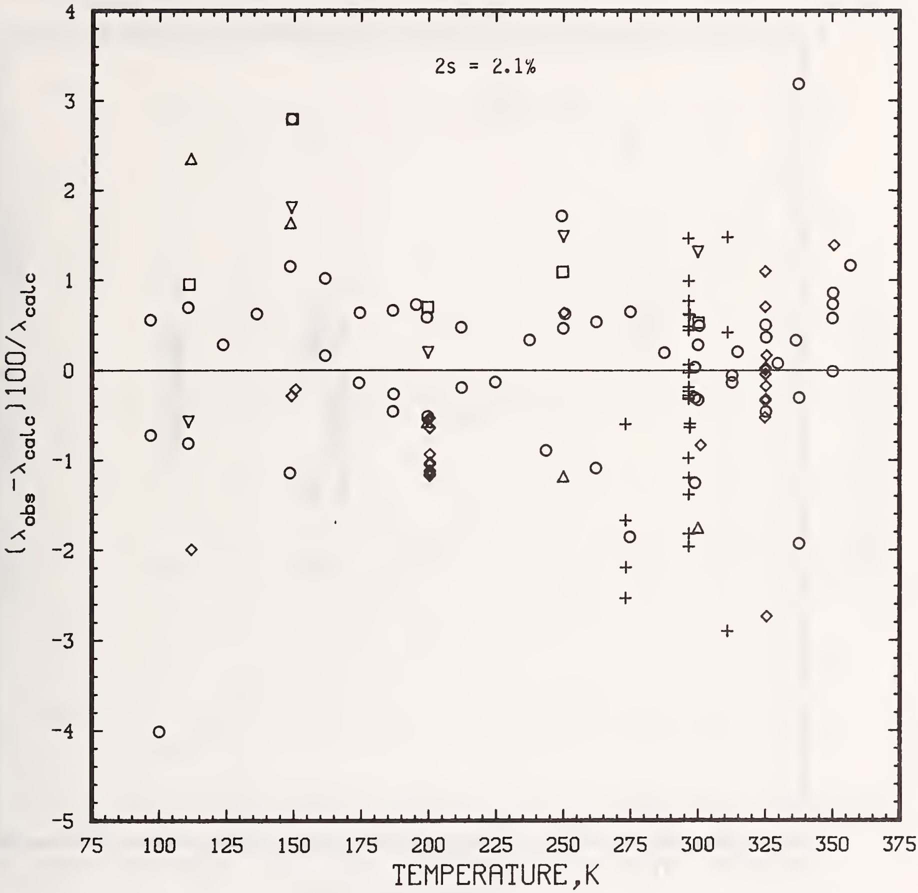


Figure 1. Deviations of measured apparent thermal conductivities from values calculated with equation (1) versus the mean temperature of the measurements at densities from 10.5 to 16 kg/m$^3$.

○ - CCE Spec. 1
△ - CCE Spec. 2
□ - CCE Spec. 3
▽ - CCE Spec. 4
◇ - CCE Spec. 5
+ - CBT

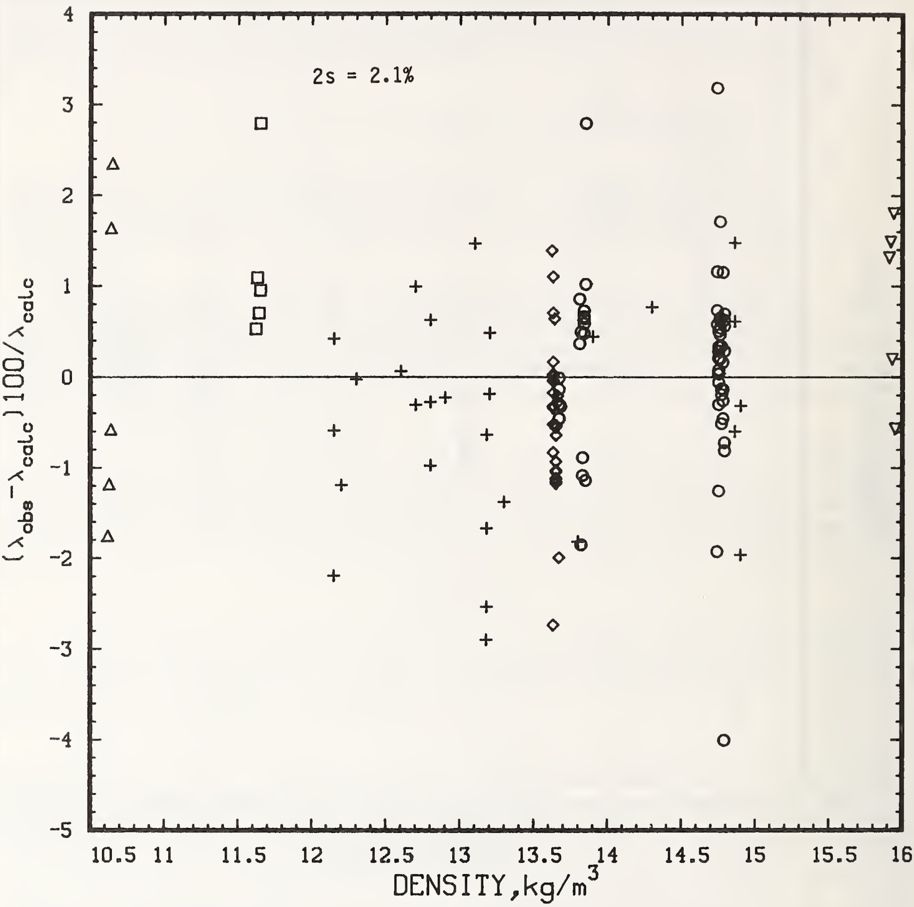


Figure 2 Deviations of measured apparent thermal conductivities from values calculated with equation (1) versus the bulk density of the specimens at temperatures from 100 to 360 K.

○ - CCE Spec. 1
△ - CCE Spec. 2
□ - CCE Spec. 3
▽ - CCE Spec. 4
◇ - CCE Spec. 5
+ - CBT

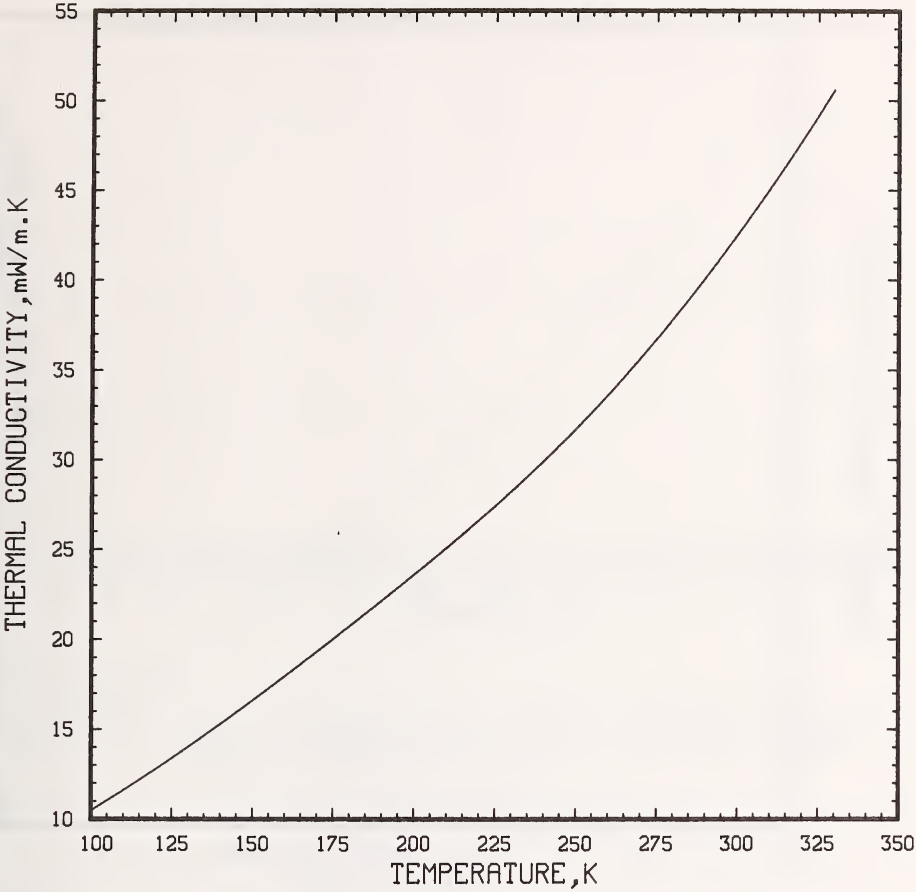


Figure 3  Thermal conductivity as a function of temperature at a density of 13 kg/m$^3$ as calculated from equation (1).

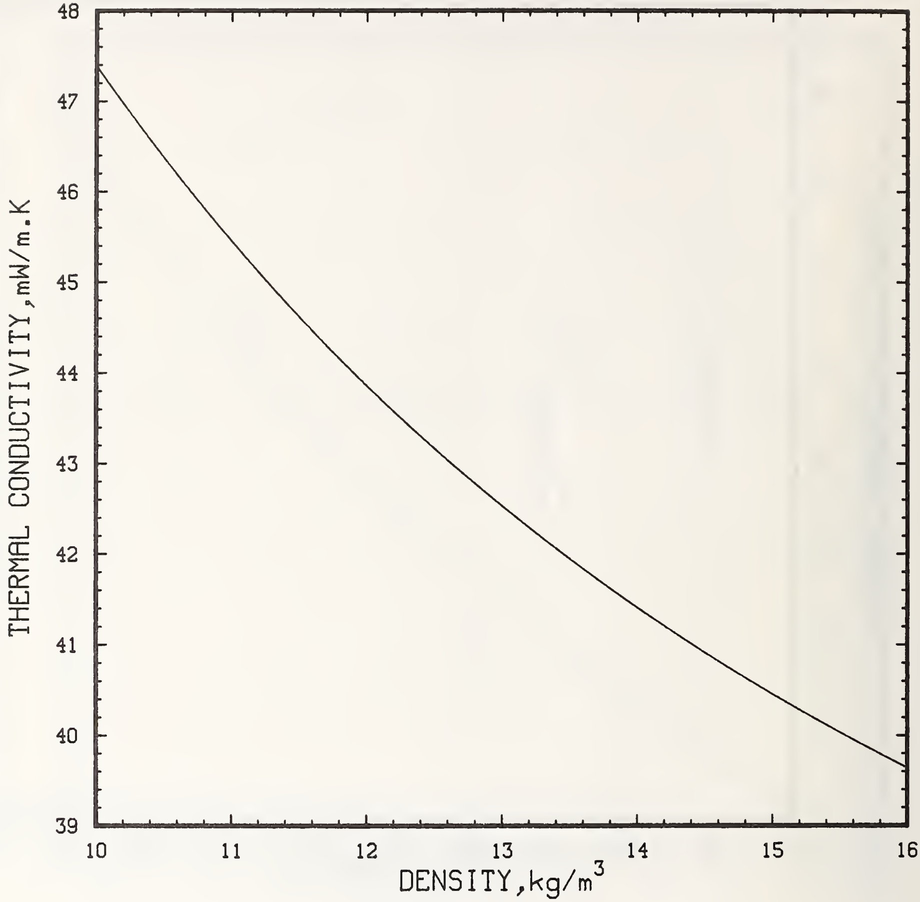


Figure 4 Thermal conductivity as a function of bulk density at a temperature of 300 K as calculated from equation (1).

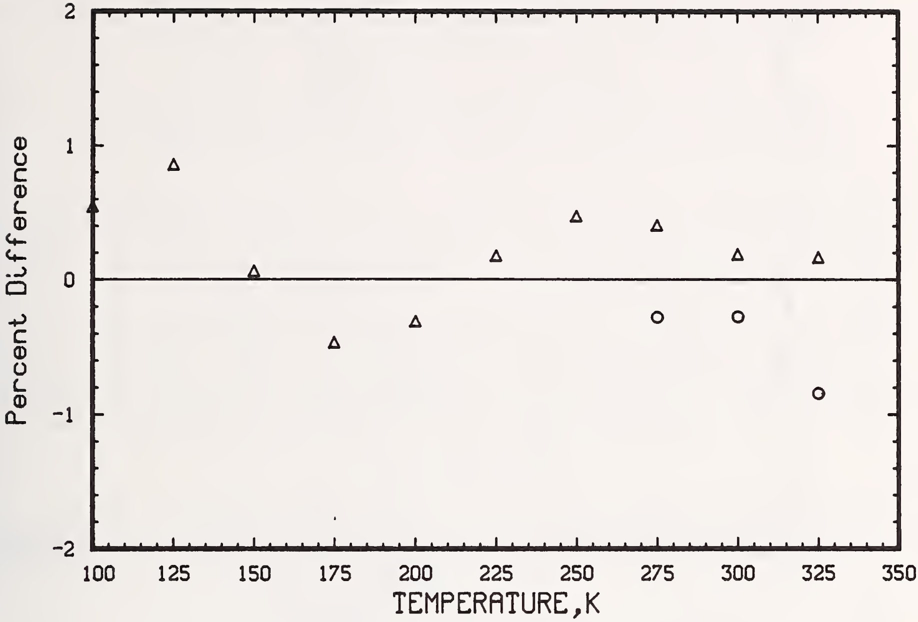


Figure 5 Comparison of equation (1) to previously published equations as a function of temperature at a density of 14.75 kg/m$^3$. Percent Difference = $(\lambda_i-\lambda_{eq.1})100/\lambda_{eq.1}$.

o - Round Robin Model [11]
Δ - Smith and Hust [9,10]

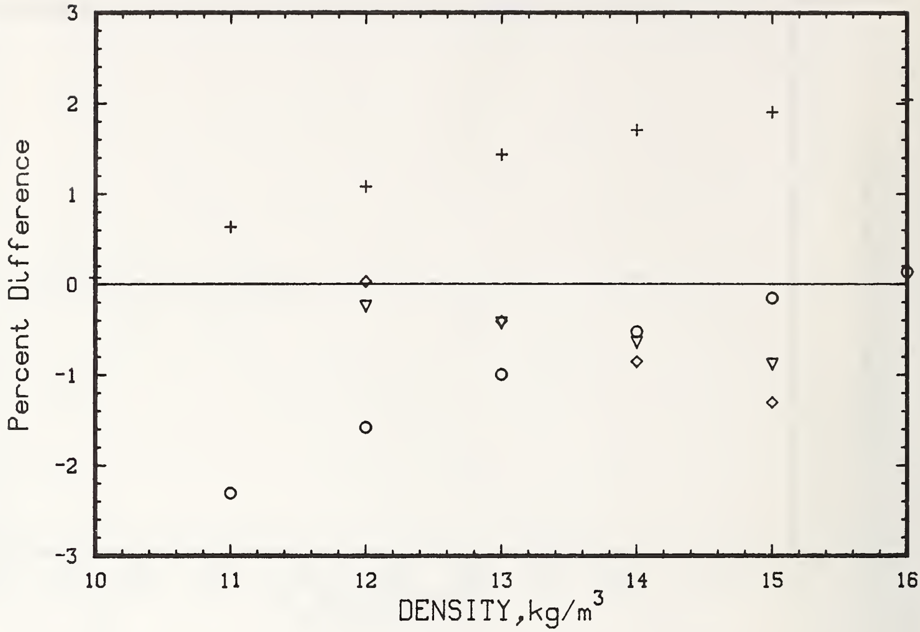


Figure 6 Comparison of equation (1) to previously published equations as a function of density at a temperature of 297 K. Percent Difference $= (\lambda_i - \lambda_{eq.1})100/\lambda_{eq.1}$.

○ - Round Robin Model [11]
▽ - GHP [12]
◇ - HFM [12]
+ - HFM [14]

used for this SRM, the difference as a function of density is probably an indication of measurement uncertainty.

The supplier of this material performed numerous characterization measurements at a temperature of 297 K using heat flow meter apparatuses of various sizes. They reported that the following equation described their apparent thermal conductivity values as a function of density, $\rho$, within the imprecision of the data: $\lambda = 28.57 + 179.6/\rho$ where $\lambda$ is in $mW \cdot m^{-1} \cdot K^{-1}$ and $\rho$ is in $kg/m^3$. Calculated values from this equation are compared to equation (1) in figure 6. This curve is nearly parallel to the curve for the round robin equation [11]. Since the round robin equation is based on NBS data, a systematic difference between the supplier's measurements and NBS measurements is noted.

Another comparison that is useful for SRM utilization is with respect to the equation presented by Rennex [12], $\lambda = 25.3 + 212/\rho$, for the CBT GHP data at a temperature of 297 K. Figure 6 shows that the equation presented by Rennex differs by less than 1% from equation (1).

The NBS-HFM apparatus with plate dimensions of 61 x 61 cm (24 x 24 in) and meter dimensions of 25 x 25 cm (10 x 10 in) was used to measure 75 specimens from this lot at 297 K. Rennex [12] reported these data and an equation describing the data to within about $\pm 2\%$. This equation, $\lambda = 24 + 229/\rho$, is compared to equation (1) in figure 6. The deviations of the two equations are well within 1% at the low density end, but exceed 1% at the higher densities.

## 6. Certified Values

For certification purposes, values of thermal resistance, R, are desirable. Values of R at a thickness of 2.54 cm (1 in), $R_o$, calculated from equation (2) are listed in Table 4 in units of $m^2 \cdot K \cdot W^{-1}$.

$$R_o = 0.0254/\lambda(T,\rho) \tag{2}$$

The as-tested thickness will most likely be slightly different from 2.54 cm. The R values at different thicknesses, L, are calculated from

$$R = R_o L/0.0254 \tag{3}$$

where R is the thermal resistance at the tested thickness, and $R_o$ is the certified value interpolated from the table or calculated from equation (2).

It should be noted that this material is certified only for thicknesses within the range of the tests reported, nominally 2.54 cm (1 in). The specimens should be in good contact with the apparatus plates, but compression to a thickness less than 2.4 cm should be avoided. Reference 13 may aid the user in connection with the compression properties and homogeneity of this material.

Values of thermal resistance of this SRM are expected to be within 3% of the computed values at temperatures from 250 to 330 K, and increasing to 5% at 100 K. These estimates are based on the experimental data and include both material variability and measurement uncertainty.

Table 4. Certified Values of Thermal Resistance of a 2.54 cm Thick Specimen, $R_0$, as a Function of Density and Temperature. (These values have been corrected for the thermal expansion of the measurement plates.)

| | Density ($kg \cdot m^{-3}$) | | | |
|---|---|---|---|---|
| Temperature (K) | 10 | 12 | 14 | 16 |
| 100 | 2.475* | 2.443 | 2.403 | 2.358 |
| 110 | 2.219 | 2.202 | 2.176 | 2.144 |
| 120 | 2.000 | 1.995 | 1.979 | 1.957 |
| 130 | 1.812 | 1.816 | 1.809 | 1.795 |
| 140 | 1.649 | 1.661 | 1.661 | 1.654 |
| 150 | 1.508 | 1.526 | 1.532 | 1.530 |
| 160 | 1.386 | 1.409 | 1.420 | 1.422 |
| 170 | 1.279 | 1.306 | 1.321 | 1.328 |
| 180 | 1.185 | 1.216 | 1.234 | 1.244 |
| 190 | 1.102 | 1.136 | 1.157 | 1.170 |
| 200 | 1.027 | 1.064 | 1.088 | 1.104 |
| 210 | 0.960 | 0.999 | 1.026 | 1.043 |
| 220 | 0.898 | 0.939 | 0.968 | 0.988 |
| 230 | 0.842 | 0.884 | 0.914 | 0.936 |
| 240 | 0.789 | 0.832 | 0.864 | 0.887 |
| 250 | 0.739 | 0.783 | 0.816 | 0.841 |
| 260 | 0.693 | 0.737 | 0.771 | 0.796 |
| 270 | 0.650 | 0.694 | 0.728 | 0.754 |
| 280 | 0.609 | 0.653 | 0.688 | 0.715 |
| 290 | 0.571 | 0.615 | 0.649 | 0.677 |
| 300 | 0.536 | 0.579 | 0.613 | 0.641 |
| 310 | 0.503 | 0.546 | 0.580 | 0.607 |
| 320 | 0.472 | 0.514 | 0.548 | 0.575 |
| 330 | 0.444 | 0.485 | 0.518 | 0.545 |

*$R_0$ values are in units of $m^2 \cdot K \cdot W^{-1}$

## 7. Summary

Measurements and data analysis are presented to establish a lot of glass fiberblanket as an SRM of thermal resistance for temperatures from 100 to 330 K and densities from 10 to 16 kg/m$^3$. A model is presented that describes the data over the above temperature and density range to within the imprecision of the data. Comparisons to previously published values for similar material are presented.

## 8. Acknowledgments

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The apparent thermal conductivity data that provide the basis for the certification of glass fiberblanket as an SRM of thermal resistance are reported and analyzed. Detailed analysis and intercomparisons of NBS and other published data are given. These data are represented by an equation describing the dependencies of the data on temperature and density. Certified values of thermal resistance are given for temperatures from 100 to 330 K and densities from 10 to 16 kg/m$^3$.


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apparent thermal conductivity; density; glass fiberblanket; Standard Reference Material; temperature; thermal resistance

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